

# Approaches Towards Visual 3D Analysis for Digital Landscapes and Its Applications

Juri ENGEL and Jürgen DÖLLNER

## Summary

This contribution outlines approaches towards automatic visual 3D analysis of virtual 3D landscape models. We introduce different notions and definitions of concepts and functions for visual 3D analysis and outline a generic function that determines visual analytic measures among objects of landscape models. This class of functions can be used as a general tool to derive various landscape characteristics and measures on a per-object basis. We also show how these tools can be efficiently implemented to cope with large, complex landscape models. The approach exemplifies how landscape models can be used in the scope of analysis and simulation, which possibly will lead to a class of metrics and characteristics that can be automatically determined and, thereby, may help to systematically characterize and compare landscape plans and concepts.

## 1 Introduction

Digital 3D landscape models provide a powerful computational framework for organizing, managing, and visualizing complex spatial information. Hence, manifold applications can be developed on top of these models, including functions and tools for analyzing these models. One class of analysis represents the *visual 3D analysis*, i.e., the analysis of landscape models based on their 3D geometry and taking into account visibility and visual contact of landscape models.

One specialized function of visual 3D analysis represents *visual contact* analysis with obvious applications, e.g., placement optimization for outdoor media objects such as billboards to ensure a high degree of visibility from the pedestrian or car-driver perspective or detection of landmarks (BRENNER ET AL., 2003) that can be defined as objects with significant higher visibility than the surrounding landscape.

*Visual contact* analysis is in its simplest form testing for visibility, i.e., a virtual observer is in visual contact to a target, if the observer can see parts of or the entire target. However, this concept can be extended by a quantification and qualification of the visual contact. For *quantification*, the visual contact is determined by the amount of the visible part of a target that is seen by an observer. For *qualification*, the visual contact is weighted by different quality criteria according to the viewing circumstances, i.e. the distance between an observer and a target, the angle between the surface normal of a target and the viewing direction and the viewing behavior of a virtual observer.

Various higher-level functions can be defined based on visual contact. For instance, we can determine for a landscape object the degree of visual contact to certain classes of other

landscape objects such as vegetation, water areas, and sky. For example, the amount of visual contact to these objects as seen through windows of a building model characterizes the viewing quality of the corresponding room – a room characteristics results that can be used in urban planning processes. Other applications can be found in the domain of public safety and security planning: The visual contact measures of public places can be used as spatial planning criteria for the security forces in charge. One of these applications is the basis of this work and is described in detail below.

## 2 Related Work

GIS provide a rich collection of analysis functionality for 2.5D models such as visibility computation, which has been considerably researched (e.g., FISCHER, 1994; FRANKLIN, 2002; HAVERKORT ET AL, 2009; O’SULLIVAN ET AL., 2001). For 3D analysis, however, only few techniques have been established as general purpose functionality. For example, although it is possible to add 3D features (i.e., imported from CAD or a geo-database) to the virtual environment in ArcGIS (Release 9.3), the visibility analysis (Viewshed, Observer Points) is still performed solely on the 2.5D terrain. To consider additional features such as vegetation, a new raster (or TIN) layer with vegetation heights is added to the terrain, which remain in 2.5D. Therefore, “viewshed analysis in GIS is rarely applied to urban settings because the operation is based on raster data or TIN” (YANG ET AL., 2007). In contrast, “CAD systems can handle full 3D data, but are limited since they do not handle topology and semantic properties and do not offer the GIS functionality required” (GRÖGER, 2004). Furthermore, the visibility analysis is limited to punctual observers and is “assessed as a Boolean phenomenon in ... GIS and CAD systems” (SKOV-PETERSEN, 2007). Our approach does not reduce the objects to mathematical points, can handle full 3D environments including bridges, tunnels, and vegetation, and quantify and qualify the amount of visual.

In many application domains, visual analysis and simulation play a major role. For example MURRAY ET AL. (2007) developed a public-safety decision support system that optimizes coverage for security monitoring (e.g., surveillance cameras), whereby the computation is based on discretized, grid-converted 2.5D representations. In the scope of urban design processes, V. BILSEN ET AL. (2008a), who see “a shift from 2D to 3D analysis, which opens up a whole range of possible new applications”, discuss and compare discrete versus continuous approaches to 2.5D visibility analysis based on a mathematical visibility model (V. BILSEN, 2008b). Our approach does not discretize the 3D virtual environment, but it is based on image analysis of discrete G-buffer contents, while the approximation error (and the incremental computation) can be controlled by the resolution of the G-buffers. *Geometric buffers* (G-buffers) (SAITO ET AL., 1990) form an enriched image space whereby each pixel contains additional information, i.e., depth, normal, object type, or id.

GROSS M. (1991) introduced an approach for analyzing visibility by 3D perspective transformations. He coded the rendered objects by color and counted the according pixel in the rendered image. BISHOP ET AL. (2000) used additionally depth images to classify objects in fore, middle, and back ground. BISHOP ET AL. (2003) discuss these techniques

stating that these “have considerable benefit over the long standing 2.5D GIS approach”. Our approach is not limited to color or depth – any information of the G-buffers is available for the analysis. Additionally, we exploit modern graphics hardware to accelerate computation.

In the scope of landscape planning, CAVENS ET AL. (2004) introduce a view-based 3D analysis method that relies on the simulation of viewing behavior of agents to derive metrics about the visual quality of planned recreation areas, modeled by virtual 3D landscapes. Visibility analysis has been applied to detect landmark buildings (BRENNER ET AL., 2003) and, more general, saliency features (NOTHEGGER, 2004). With our approach, such methods can be implemented and configured in a systematic and canonical way.

### 3 Visual Contact Analysis in Landscape and Urban Planning

In urban planning decision processes, stakeholders frequently want to compare two or more planning proposals on an objective basis. Visual analysis provides means to derive metrics that allow stakeholders to classify and compare spatial characteristics and properties.

In an ongoing research project related to land management, we have analyzed a landscape model with a park area and its neighborhood regarding public safety issues. The park is one of the few public parks in a dense urban area (Fig. 1), and supposed to be a place for recreation, but unfortunately used by drug dealers as a kind of central market place. To improve the situation, the questions are how safety guards could optimize their control while patrolling around the streets next to the park and how the sense of personal safety can be increased.

The perception of personal safety is strongly related to the presence of visual enclosure (STAMPS, 2005). The visual 3D analysis of the park area helps to detect areas that are visual concealed (Fig. 2) and thus are difficult to observe from the patrol paths and induce a sense of fear. The analysis results can be used as a decision support for modification of the landscape and vegetation in the park to reduce these areas or to optimize the control paths of the security forces and to focus their attention on these areas.



**Fig. 1:** Park area, shown in the virtual 3D landscape model with photorealistic appearance. (*Google Earth*)



**Fig. 2:** Example of an area that is visual concealed and thus is difficult to observe and cause a sense of fear.

## 4 Objects Participating in the Analysis

The objects of 3D virtual environments can be classified with respect to different roles they adopt during the analysis process. The visual analysis is performed for *analyzed objects*. We assume that its surface can be geometrically represented by a finite collection of facets. For all surface points of these facets the 3D virtual environment is evaluated with respect to a specified set of objects. These objects are called *target objects* and can be selected by criteria such as object type and state.

In our use case, the entire park area has served as analyzed object. For all points in the park we determine the simultaneous visual contact to the entire patrol route, assuming that security guards are equally distributed along that route. The result can be interpreted as the degree of visual contact of a given park position and the patrol “observation space”.



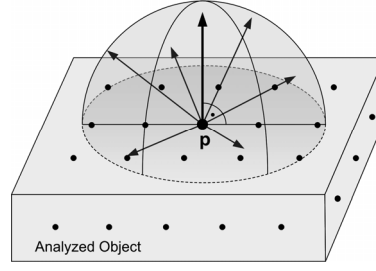
**Fig. 3:** Example for auxiliary objects representing potential eye positions of pedestrians walking along a park route.

As the patrol path is specified as a set of georeferenced 2D lines we construct vertical 3D polygons along these lines and positioned at the height of the human eye (Fig. 3). These can act as target objects for an analysis evaluating the visual contact to observers walking on the path. We refer to these objects as *meta objects*. Meta objects introduce additional, abstract analyzed or target objects. Meta objects and proxy objects are *auxiliary objects*. *Proxy objects* substitute complex 3D geometry and, therefore, accelerate the computation. For example, a detailed 3D tree model can be replaced by a cylinder modeling the trunk and a 3D sphere modeling the tree crown.

## 5 Visual 3D Analysis Concept

Figuratively speaking, the discrete, visual analysis technique is based on a virtual sensing device, which traverses surfaces of analyzed objects (Fig. 4), generates off-screen views and performs an image-based analysis of the *Geometric buffers* (G-buffers).

The sensing device sends out a bundle of rays from a surface point, each of which detects one or more characteristics of the 3D virtual environment  $E$ . For a pragmatic, discrete implementation we approximate the ray bundles by 3D frustums and detect target objects based on G-buffers and occlusion queries.



**Fig. 4:** Working principle for sensing the 3D virtual environment. The evaluation is performed for a finite set of sampling points on surfaces of analyzed objects.

To formalize the 3D sensor, we introduce a sensor function. The sensor function  $S$  is evaluated at the surface of an analyzed object at a position  $p$  as follows:

$$S = \int_V \int_{\Omega_v} f(p, \text{hit}(E, \omega)) d\omega dv$$

In this definition,  $\Omega$  denotes the scope of the sensor, i.e., all directions in which sensor rays  $\omega$  can be sent out. The *analysis function* itself is defined by the function  $f$ , which evaluates the rays  $\omega$  sent out from  $p$ , whereby the *hit* function determines the object that is hit by  $\omega$  and that is closest to  $p$ . In our use case  $f$  returns 1 for the meta objects along the path and 0 else.

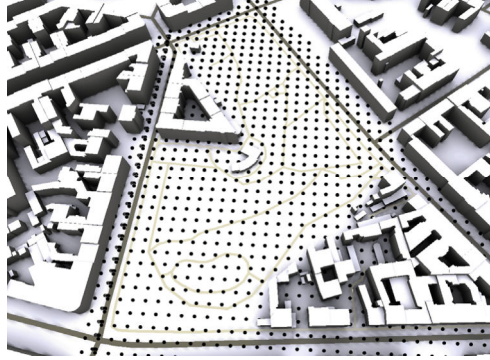
The sensor function is further extended by the *viewing behavior*  $V$  of hypothetical observers that is represented by varying the sensor scope  $\Omega$ ; the viewing settings  $v$  can restrict, weight, and/or modify the way sensor rays are sent out.

## 6 Implementation

We perform the visual 3D analysis on a discrete, finite subset of all points of the analyzed facets. Therefore, the faces of the analyzed object representing the park area are rasterized (Fig. 5). The sampling rate is variable and can be adjusted by the user, e.g., one sample point every five meter. The sampling rate control the approximation error and the time required for the analysis.

The visual 3D analysis process can be refined by simulating different viewing behaviors and preferences. For this purpose, sample points are paced in the height of the human eye to simulate human observers. Additionally, multiple directions for the virtual camera at every sample point are created. To determine the visual contact to the entire patrol path we have to simulate a 360-degree view. Therefore, we use four cardinal directions and a field of viewing angle of  $90^\circ$ .

For every direction the visual contact is determined separately during the buffer processing step. These results are combined to a single measure for the corresponding sample point by summing the single values. The sensor places the virtual camera sequentially on every sample point, orients it to every sample direction, and renders the prepared scene in off-screen mode to generate the required G-buffers.



**Fig. 5:** Sampling of the park area. The sample density is one sample point every 5 meter.

The sensors scope is approximated by performing the analysis computation on a discrete representation of all rays that is a projection of the 3D scene at a sample point. By increasing or decreasing the resolution we can directly control the computational complexity of the analysis and the approximation error. The implementation uses the finite, discrete viewplane  $[0; N[ \times [0; M[$  to compute an approximated, quantified result:

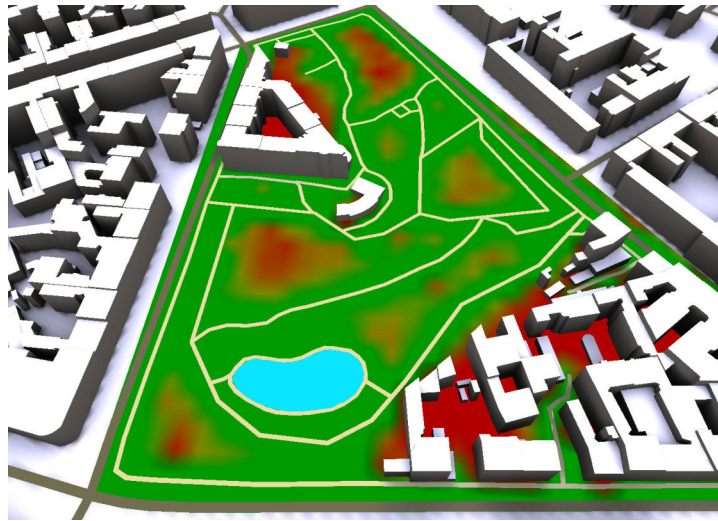
$$S \approx \sum_{\phi \in \{0^\circ, 90^\circ, 180^\circ, 270^\circ\}} \frac{1}{|N| \cdot |M|} \sum_{i \in N} \sum_{j \in M} f(p, \text{hit}(E, \omega_{i,j}))$$

The evaluation of the sensor function is done by processing the G-buffers. The application specific analysis functions can be implemented in multiple ways. Functions that operate only on a single sensor ray, that is a single pixel in a G-buffer, can be implemented as shaders. Functions that need the whole sensors scope of view as input process the G-buffers. Also, if necessary, occlusion queries (BARTZ ET AL., 1998) are performed to quantify the extent to which target objects are visible. Occlusion queries return the amount of fragments that pass all tests of the fragment pipeline (e.g., depth- and stencil-test).

With occlusion queries the visible area of the rendered objects can be determined. We turn on occlusion queries while rendering target objects. Thus, in our use case we get the visible area of the meta objects representing observers walking along the path and can, hence, derive the general visibility of the actual sampling point with respect to the patrol path.

The results of the analysis for each sampling point are mapped to one or more scalar values. For example, we can use a gray scale, e.g., white for high visual contact to control paths and black for low (Fig. 6). These values are stored in surface textures. To save texture memory and the amount of texture switches the textures are managed in a texture atlas (WLOKA, 2005). Texture atlases combine multiple textures in a single large texture.

As the results are visualized on the same position where the analysis was performed, the spatial characteristic of the analyzed attributes and their spatial relations are emphasized. To provide also the details of the analyzed objects, which can also be necessary for spatial classification of results, multi-texturing of the resulting texture and the original detailed texture can also be used.



**Fig. 6:** Results of the visual 3D analysis of the park – areas having low visual contact to the whole set of surrounding streets are marked in black.

## 7 Conclusion

We have presented a technique for automatic visual 3D analysis of virtual 3D landscape models that efficiently evaluates visual information such as visual contact by sensing the virtual 3D environment without restrictions to their geometry, topology, and design. The technique uses a discrete 3D sensing process that generates off-screen views and performs an image-based analysis of the G-buffers. Since this approach can be implemented within the programmable rendering pipeline together with multi-pass rendering, we can take full advantage of 3D graphics hardware. In particular, the technique can rapidly and incrementally generate analysis results for typical scenarios.

This technique gives access to numerous sensor inputs by geometric information and object-based information and can incorporate viewing behavior models. Thus, manifold analysis functions can be implemented.

We applied the presented technique in a use case for an ongoing research project related to land management to analyze a landscape model regarding public safety issues. The visual 3D analysis of the park area helps to detect areas that are visual concealed and the results can be used as a decision support for modification of the landscape and vegetation in the park or to optimize the control paths of the security forces.

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